Investigating ozone sources in California using AJAX airborne measurements and models: Implications for stratospheric intrusion and long range transport

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Abstract

High ozone concentrations at low altitudes near the surface were detected from airborne Alpha Jet Atmospheric eXperiment (AJAX) measurements on May 30, 2012. We investigate the causes of the elevated ozone concentrations using the airborne measurements and various models. GEOS-chem and WRF-STILT model simulations show that the contribution from local sources is small. From MERRA reanalysis, it is found that high potential vorticity (PV) is observed at low altitudes. This high PV appears to be only partially coming through the stratospheric intrusions because the air inside the high PV region is moist, which shows that mixing appears to be enhanced in the low altitudes. Considering that diabatic heating can also produce high PV in the lower troposphere, high ozone is partially coming through stratospheric intrusion, but this cannot explain the whole ozone concentration in the target areas of the western U.S.

A back-trajectory model is utilized to see where the air masses originated. The air masses of the target areas came from the lower stratosphere (LS), upper (UT), mid- (MT), and lower troposphere (LT). The relative number of trajectories coming from LS and UT is low (7.7% and 7.6%, respectively) compared to that from LT (64.1%), but the relative ozone concentration coming from LS and UT is high (38.4% and 20.95%, respectively) compared to that from LT (17.7%). The air mass coming from LT appears to be mostly coming from Asia. Q diagnostics show that there is sufficient mixing along the trajectory to indicate that ozone from the different origins is mixed and transported to the western U.S.

This study shows that high ozone concentrations can be detected by airborne measurements, which can be analyzed by integrated platforms such as models, reanalysis, and satellite data.

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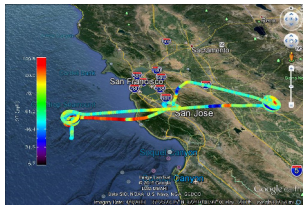
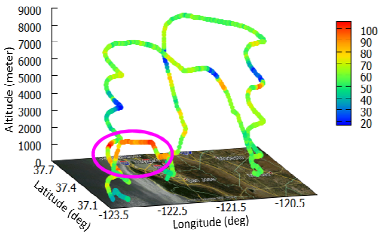
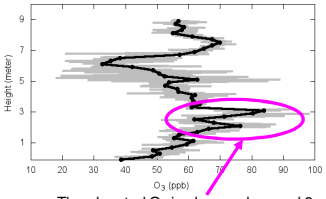
Introduction

- **On May 30, 2012 19Z, High O_3 is observed offshore near the Bay Area, detected by Alpha Jet Atmospheric eXperiment Flight (AJAX).**







- The elevated O_3 is observed around 2 – 4 km above the surface.

- The ozone is a secondary pollutant and influenced by local as well as background hemispheric concentrations through transboundary transport.
- **The current background O_3 mixing ratios are estimated to be in the range of 15-35 ppbv, contributing up to 47% towards the current U.S. Environmental Protection Agency (EPA) National Ambient Air Quality Standards (NAAQS) O_3 target of 70 ppbv.** There are also strong exceedances and evidence of air aloft impacting surface O_3 in the western U.S. [e.g. Fiore et al., 2003, Yates *et al.*, 2014]

•Thus, it is necessary to clarify the distributions and variations of O_3 sources using the high-precision data through in-situ aircraft measurement, satellite, and various models.

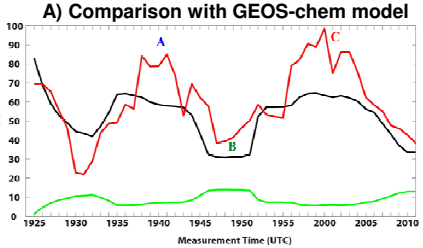
Data

- The Alpha Jet aircraft data was used on May 30, 2012, to measure spatial and temporal profiles of O_3 over Instrumentation in Starboard Wing Pod:
  - Ozone: 2B Tech (0.1Hz)
  - Greenhouse Gases (CO2, CH4): Picarro 2301-m (3Hz)
  - Tested to date up to 25000 ft and down to 1000 ft.
- NASA GSFC Lagrangian trajectory model (*Schoeberl and Sparling*, 1995).
- GMAO MERRA reanalysis data [*Bosilovich et al.*, 2011]
- WRF-STILT [*Nehrkorn et al.*, 2010]
- GEOS-Chem [*Bey et al.*, 2001]

Results

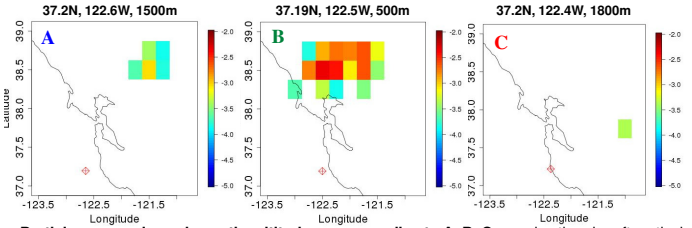
1) Local Source

A) Comparison with GEOS-chem model



- 1 minute averaged AJAX O3(red) , total O3 simulated from GEOS-chem (black), and GEOS-chem simulated, but only local O_3 with no inflow of O_3 from boundary (green).
- **Shows that local source plays a little role in O3 formation, explaining about 10-20% of the observed high O_3.**

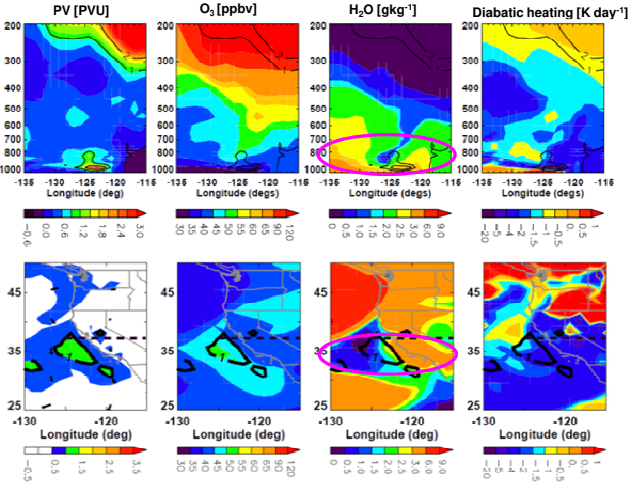
B) Footprint from WRF-STILT model



- **Particles were released over the altitude corresponding to A, B, C** covering the aircraft vertical level shown in the time series plots. The scale is the logarithm (base 10) of the footprint
- The red in footprints indicate the large surface impact on concentration change at the receptor for a unit surface flux persisting over a given time interval [mol^{-1}m^{2}s]): **thus, high O3 at the given altitudes are not largely associated with local source.**

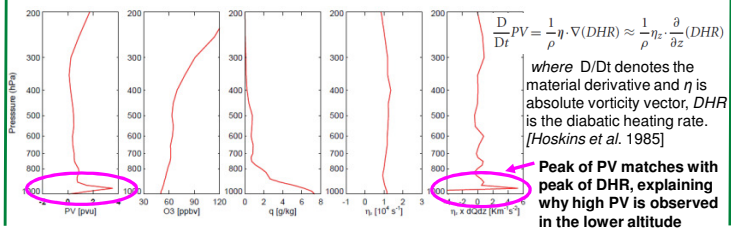
2) Stratospheric Intrusion into Troposphere

- **Vertical & Horizontal profiles (36.5 – 38.5N & 850 hPa (1.5 km))**



- High MERRA O_3 around 30-40N from 200 to 400 hPa is closely linked to the high PV in the upper troposphere and lower stratosphere. Very low MERRA H_2O supports this.
- **The descent motions can be related to the formation of high lower-level PV as it brings air with high PV values to the lower troposphere.**
- However, this still cannot explain fully why PV is so high because H_2O is not so low. H2O should be very low (i.e. the portion inside PV should be dry) if the high PV comes directly from the stratosphere, **indicating that there appears to be mixing between upper- and lower-level airs**

- **PV is modified by diabatic heating/cooling processes.**



$$\frac{D}{Dt}PV = \frac{1}{\rho}\eta \cdot \nabla(DHR) \approx \frac{1}{\rho}\eta_z \cdot \frac{\partial}{\partial z}(DHR)$$

where D/Dt denotes the material derivative and η is absolute vorticity vector, *DHR* is the diabatic heating rate. [*Hoskins et al.* 1985]

Peak of PV matches with peak of DHR, explaining why high PV is observed in the lower altitude

Implications

3) Implication of Long range transport

- **Showing that air parcels are transported from the Northern Asia across the Pacific.**

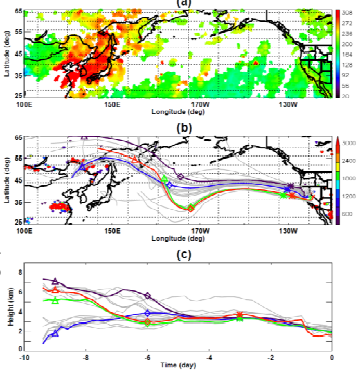
(a) CO averaged over May 21-30, 2012 obtained from MOPITT (Measurement of Pollution in the Troposphere) data

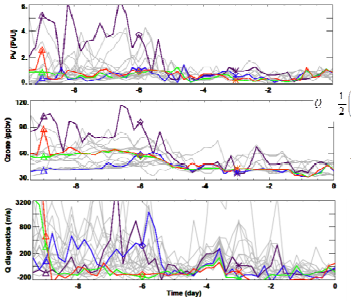
(b) Horizontal pathways of back trajectories overlaid by burned area from the Global Fire Emission Database (GFED)

(c) Vertical evolutions of back trajectories releasing data at 305K using MERRA reanalysis coming to California (day = 0).

- The color lines represent the locations similar to where AJAX passed through in terms of starting points (123-120W, 37.5N)

- **CO from emission and wildfire can be one of the source of ozone precursor.**





- **Q diagnostics**

(Haynes, 1990, Fairlie et al. 2007)

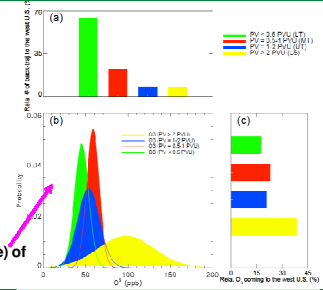
- A measure of mixing of air parcels in the large-scale flow.

$$\frac{1}{2}\left(\frac{1}{\cos\phi}\frac{\partial u}{\partial \lambda} - v\tan\phi\right)^2 + \frac{1}{2}\left(\frac{\partial v}{\partial \phi}\right)^2 + \frac{\partial u}{\partial \phi}\left(\frac{1}{\cos\phi}\frac{\partial v}{\partial \lambda} + u\tan\phi\right)$$

- *Where u, v,* is zonal, meridional wind, λ , ϕ is longitude, latitude, respectively.
- **Positive Q : efficient mixing** (the fluid elements are stretched, associated with the regions of Rossby wave breakings)
- **Indicating there are significant sources in the Asia across the Pacific, and they are "transported" through the mixing** across the Pacific.

Summary and Conclusions

- **High O_3 is detected by the in-situ aircraft measurement.**
- The elevated O_3 concentrations near the coast of the Bay Area (37.5N, 122.5W) detected by AJAX attribute to
  1) **local source (LT) ~ 15%**
  2) **transport from upper troposphere (UT)/ lower stratosphere (LS) ~ 67%**
  3) **long-range transport from the Asia (MT) ~18%**



Relative number (percentage) of O3 from different origins

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